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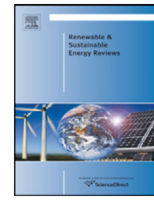

# Renewable energy sources in the Egyptian electricity market: A review

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ABSTRACT

This review paper presents an appraisal of renewable energy RE options in Egypt. An appraisal review of different REs is presented. The study shows that electric energy produced from REs in Egypt are very poor compared with other energy sources. The utilization of the renewable energies can also be a good opportunity to fight the desertification and dryness in Egypt which is about 60% of Egypt territory. The rapid growth of energy production and consumption is strongly affecting and being affected by the Egyptian economy in many aspects. It is evident that energy will continue to play an important role in the development of Egypt's economy in coming years. The total installed electricity generating capacity had reached around 22025 MW with a generating capacity reached 22605 MW at the end of 2007. Hydropower and coal has no significant potential increase. During the period 1981/82–2004/05 electricity generation has increased by 500% from nearly 22 TWh for the year 1981/1982 to 108.4 TWh in the year 2004/2005 at an average annual growth rate of 6.9%. Consequently, oil and gas consumed by the electricity sector has jumped during the same period from around 3.7 MTOE to nearly 21 MTOE. The planned installed capacity for the year 2011/2012 is 28813 MW and the required fuel (oil and gas) for the electricity sector is estimated to reach about 29 MTOE by the same year. The renewable energy strategy targets to supply 3% of the electricity production from renewable resources by the year 2010. Electrical Coverage Electrical energy has been provided for around 99.3% of Egypt's population, representing a positive sign for the welfare of the Egyptian citizen due to electricity relation to all development components in all walks of life. The article discusses perspectives of wind energy in Egypt with projections to generate ∼ 3.5 GWe by 2022, representing ∼9% of the total installed power at that time (40.2 GW). Total renewables (hydro + wind + solar) are expected to provide ∼7.4 GWe by 2022 representing ∼ 19% of the total installed power. Such a share would reduce dependence on depleting oil and gas resources, and hence improve country's sustainable development.



**Contents**



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## 1. Introduction

The growing demand in energy and concern about depleting natural resources and global warming has led states worldwide to consider alternatives to the use of fossil fuel for energy production. Several countries especially in Europe have already increased their renewable energy share 6–10%, expected to increase to 20% by the year 2020. For Egypt excellent resources of wind and solar energy exist. The future of energy in Egypt is challenging. The local demand for energy and electricity is rapidly growing at the same time where the two major energy sources of the country, namely oil and natural gas, are in a precarious situation. The Egyptian oil reserves are depleting and there are high and justifiable expectations that in the coming few years Egypt traditionally a net exporter – will be a net oil importer country. And with this depleting oil reserves situation, natural gas on the other side has to balance between two equally important roles, the role of the main energy source feeding growing local needs and the role of the main exported fuel that guarantees for Egypt an indispensable flow of hard currency. This double role can in fact cause a faster depletion of the rich natural gas reserves that Egypt currently enjoys.

Acknowledging this critical energy situation and in order to face this challenge, the Supreme Council of Energy [1] has approved in 2008 a strategy to diversify the energy sources in the electricity sector and reduce the dependency on fossil fuel by considering a larger contribution from renewable energy sources. Accordingly, the share of renewable energy in the electricity generation should reach 20% by the year 2020 excluding the share of the large hydropower plants.

The Egypt's New & Renewable Energy Authority (NREA) was set up in 1986, with the establishment of testing & certification laboratories and personnel training. The practical work of NREA began with assessing renewable energy resources and investigating the choices of different technologies through studies and pilot projects, as well as introducing some of these technologies to the Egyptian market and supporting the initiatives of local industry. In pursuit of its reform agenda, the Egyptian government has set an ambitious renewable energy program to generate 500 MW of solar energy, more than 600 MW of wind power, and 600 MW of hydroelectric power by 2017 [2]. Egypt has large deserts and abundant land mass, only 7% of which is heavily populated. These areas are well suited to host renewable energy projects to increase the country's share of renewable energy as well as to export excess energy to Europe. The Egyptian national grid is extensive, providing over 99% of the population with modern electric energy services. Currently, grid connected renewable energy projects in Egypt enjoy the right of access and priority in dispatching.

Through the current world concern with searching about new energy resources; supporting Renewable Energy Technologies (RETs) already in use, increasing the efficiency of current systems and promoting RET world wide, the United Nations and other international organizations are supporting a lot of projects and programmes especially in developing countries.

A few numbers of studies were carried out on applied photovoltaic & wind power and their applications in Egypt. The wind energy potential at the Red Sea and the Mediterranean coast along with some interior parts of Egypt were analyzed in the study about utilizing wind energy in some remote areas to feed part of the need of some isolated communities. The studied areas were on the north coast, the red sea coast and the east of Oweniat. The Red Sea coast was again the scope of the work presented by some researchers where an assessment of several regions on the red sea coast was conducted. In their study the researchers have estimated based on a technical and an economical assessment the cost of generating wind electricity in the studied regions and found it to be very competitive when compared to the other sources of electricity generation. With respect to the coast of the Mediterranean Sea, have evaluated the energy potential along with the generation cost analysis of ten locations and found that three of the ten locations, namely, Marsaa Matrouh, Sidi Barani and Eldabaa were well suited for wind electricity generation given their favorable wind characteristics. The same authors have also identified the wind electric potential of the coastal city; Hurghada. As a result of fossil energy problem and to introduce a solution for the energy future in Egypt, such a review is doing.

In this paper, the decision to harness renewable energy such as solar energy, and wind energy, to auto-produce electricity will be assessed from the perspective of an industrial electricity customer. In fact, such a decision to auto-produce electricity in order to feed the industry operation may become soon a potential investment decision given the expected increase in electricity prices that the industrial customer will witness with the elimination of electricity subsides [3]. Therefore this l paper is addressing a particular research question which is: Will the installment of both photovoltaics and wind energy conversion systems by an energy intensive customer be an economically feasible decision? And

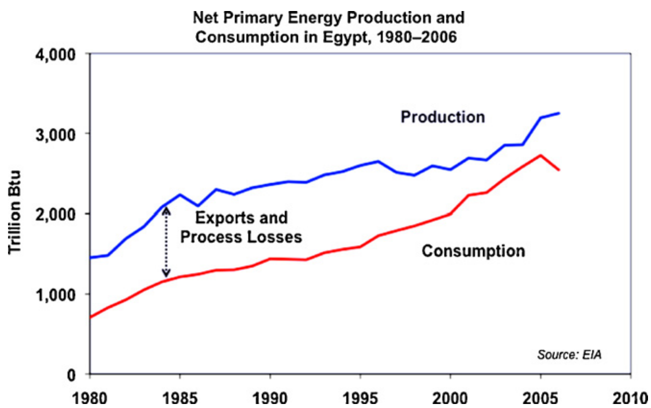


**Fig. 1.** Net primary energy production and consumption in Egypt, 1980–2006.

under which conditions will such an investment decision pay off. Also, it gives an overview about the renewable energy in Egypt.

This paper is organized into the following sections: general energy context in Egypt in Section 2, electricity consumption and production in Section 3, while drivers for renewable energy in Section 4, photovoltaic market and supply chain in Egypt in Section 5, wind energy market and supply chain in Egypt in Section 6, summary profile of PV and wind energy supply sectors in Section 7 and finally the conclusions are in Section 8.

## 2. General energy context in Egypt

Egypt's energy production and use are growing rapidly. Between 1998 and 2006, net primary energy production grew from 2477 trillion Btus to 3251 trillion Btus, an average annual increase of 3.5% as seen in Fig. 1. Egypt boasts an impressive level of access to modern energy services, with 99.3% of the population having access to electricity [2]. In 2003/2004, electricity accounted for 19.3% of final energy consumption. Fig. 2 shows the distribution of final energy consumption among different sectors of Egypt's economy [4–6].

Energy is essential for Egypt's economic growth for two primary reasons: it is a key direct driver of domestic development, and it represents a source of foreign currency associated with fuel exports. The country's current primary energy sources are oil products, natural gas, hydropower, and to a very limited extent RE resources.

### *2.1. Oil and natural gas*

Crude oil production in Egypt peaked in 1996 at 921,667 barrels/day, or 336 million barrels/year (bbl/y)[7]. By 2008, production

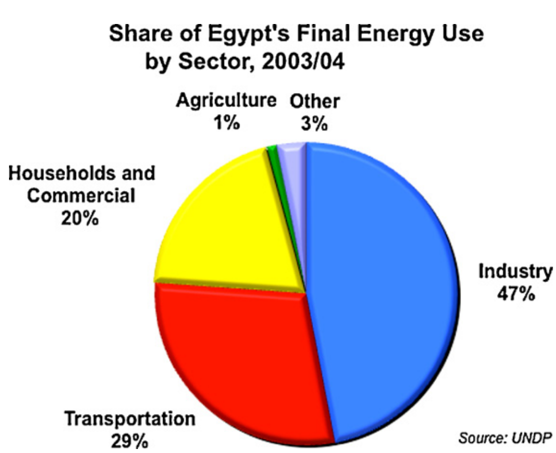


**Fig. 2.** Share of Egypt's final energy use by sector, 2003/2004.

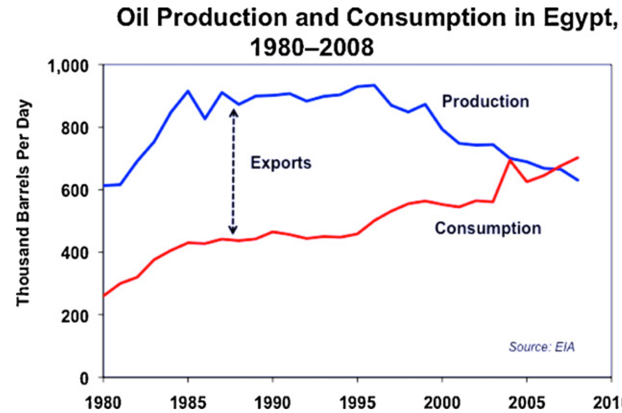


**Fig. 3.** Oil production and consumption in Egypt, 1980–2008.

had fallen to 602,530 barrels/day (220 million bbl/y), an average annual decrease of 3.4% [8–12] as shown in Fig. 3.

Production continues to decline despite new discoveries and improvements in oil recovery techniques at mature fields. In 2008, remaining oil reserves were estimated at 3.7 billion barrels; the last major discovery was the Sakkara field in 1989. Egypt's consumption is expected to have surpassed domestic production (or, according to some estimates, will surpass it within the next few years), making the country a net importer of oil.

In contrast, domestic natural gas production continues to rise, from 477 billion cubic feet (Bcf) in 1997 to 1678 Bcf in 2007, an average annual increase of 14% as in Fig. 4. Egypt's gas production began to exceed its demand in 2003, and by 2006 the country became a major exporter, supplying 597 Bcf to the international market that year.

Official estimates of proven gas reserves are 68.2 trillion cubic feet in 2006/2007 [7]. Independent international experts estimate reserves to be anywhere from 58.5 trillion cubic feet to 63 trillion cubic feet [13–15]. There is growing concern among some experts that Egypt's gas reserves could be depleted as early as 2020 and that Egypt could face a deficit between consumption and production [16–22].

Some experts who were interviewed for this study (and who insisted on remaining anonymous) believe that Egypt has been a net oil importer for several years. As for natural gas, experts believe that reserves could be depleted anytime during the period 2017–2032, with depletion in 2020 or the years that immediately follow being rather unlikely based on government announcements that include significant room for fossil fuel resources in the national energy portfolio in 2020 [23,24]. The forecasts differ according to assumptions about the effectiveness of governance, energy

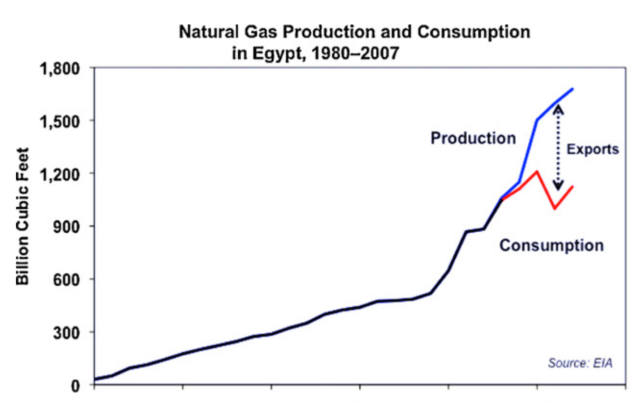


**Fig. 4.** Natural gas production and consumption in Egypt, 1980–2007.

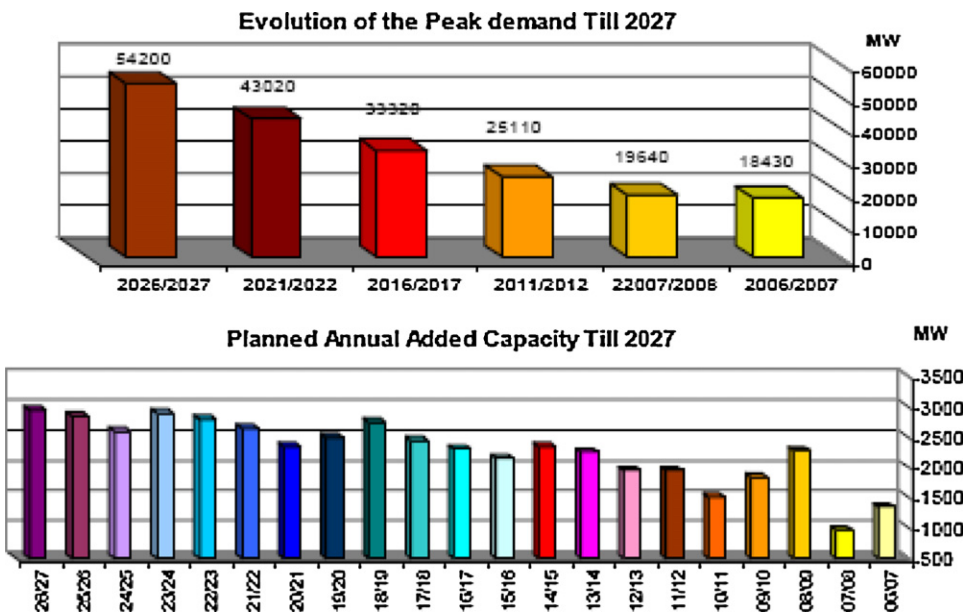


**Fig. 5.** Projected increase in annual electricity demand and planned added capacity in Egypt, 2006/2007–2026/2027 [11].

conservation measures undertaken, level of globalization and international cooperation, and local conditions. Although projections vary with regard to when Egypt's fossil reserves will be depleted, most analysts agree that Egypt will face major challenges in meeting its growing energy needs in the near to medium term.

## 3. Electricity consumption and production

Electricity accounts for a significant share of Egypt's energy production and use. As mentioned above, electricity production accounted for some 19% of final energy consumption in 2004, and this share continues to rise.

### 3.1. Electricity consumption

Electricity consumption in Egypt is increasing rapidly. According to government figures, the commercial sector experienced the most rapid average annual growth over the last five years (10.2%), followed by public utilities (9.4%), government (8.3%), agriculture (7.9%), residential (7.5%), and industry (5.9)% [8]. Peak load demand has increased at an average annual rate of 8.1% over the last 10 years, reaching 18430 MW in 2006/2007 [9] as shown in Fig. 5.

In 2006/2007, Egypt's total electricity consumption was 115.4 million megawatt-hours (MWh) [25]. Assuming varying degrees of saturation in the end-use sectors, Egypt's electricity use is projected to increase at an average annual rate of 5.7% from 2005 to 2030 [21]. Annual growth is expected to be 6.6% for the period 2005/2006 to 2010/2011, then declining to 5.8% for the period 2010/2011 to 2020/2021, and falling to 5.2% for the period 2020/2021 to 2029/2030 [27]. Demand is projected to reach 54,200 MW by 2026/2027 [26].

Egypt's two major end-users of electricity are the residential sector and the industrial sector. In 2006/2007, these accounted for 36% and 35%, respectively, of the country's total electricity consumption [11]. The two sectors have also been major drivers of the rapid growth in electricity demand, accounting for 67% of the total growth in the last 5 years [12].

Peak load demand is expected to continue increasing at average rates of 6–7% for the next decade [11]. Sources vary, however, on the precise rate of expected growth of the industrial and residential sectors. The main drivers of increased electricity demand are

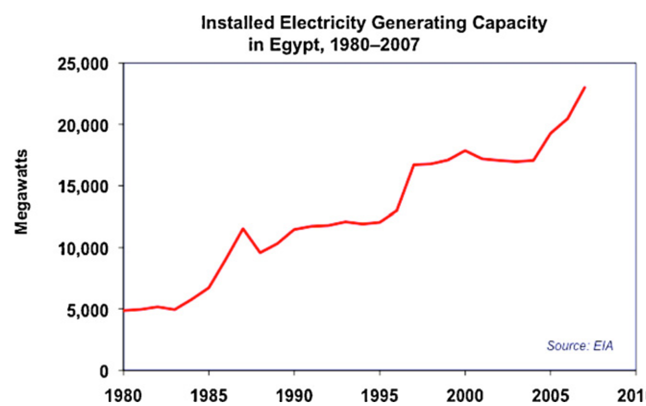


**Fig. 6.** Installed electricity generating capacity in Egypt, 1980–2007 [12].

population growth, construction of housing units, and industrial development. This trend is likely to continue into the foreseeable future, although it may face temporary interruptions due to factors such as regional political turmoil.

### 3.2. Electricity production

To meet rising electricity demand, Egypt's installed electricity generation capacity has grown steadily for the last 5–6 years, reaching 23,000 MW in 2007, see Fig. 6. New capacity installations between 2004 and 2007 averaged 1500 MW/year. Egypt plans to reach a 32,000 MW capacity during the next five years. The additions are expected to come mainly from thermal sources that use highly efficient combined-cycle production technologies.

Egypt will need to improve its power infrastructure in parallel with its increasing capacity.

In 2006/2007, natural gas fuel represented 69% of the total installed power generation capacity, oil 16.9%, and hydropower 12.8% as in Fig. 7. Hydro generating capacity remains constant at 2700 MW, and the potential for increase is limited [28]. Non-hydro RE (predominantly wind) represented 1% of the total installed generation capacity in 2006/2007, and electricity from industrial co generation units represented some 0.3% of the total [29].

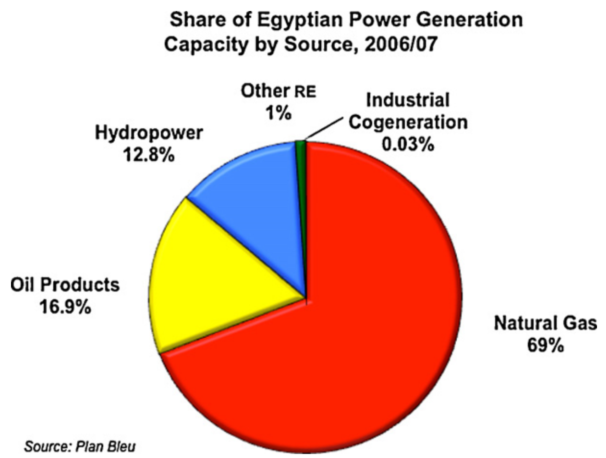


**Fig. 7.** Share of Egyptian power generation capacity by source, 2006/2007.

## 4. Drivers for renewable energy

Egypt's dependence on fossil fuels—with its depleting oil resources, controversial estimates for natural gas reserves, and rising electricity demand and energy generation—represents a clear call for action. Energy-efficiency improvements offer enormous potential and must be taken more seriously. However, given the expected significant gap in resources to meet growing electricity demand and the efficiency limitations of available power-production technologies, the Egyptian government has chosen to consider nuclear power and RE sources as new energy options.

### *4.1. Overview of renewable energy in Egypt*

The RE resources with the greatest potential for widespread application in Egypt are solar and wind, both of which are substantial in the country. This section looks at the potential for solar and wind energy in Egypt, their current status, and government policies to promote RE deployment and technology development. Renewable energy represents an important option for the change in energy mix. In 2009, renewable energy, mainly hydropower, accounted for 12% of Egypt's electricity generation. Government policy has consistently emphasized hydropower, but there is a view that most potential hydro resources have been already developed. Egypt's hydropower potential is about 3664 MW with an estimated energy of 15,300 GWh/annum. There are currently five main hydropower generation locations, all of which located on the River Nile. Almost all the electricity generation comes from the Aswan High Dam and the Aswan Reservoir Dams. The Aswan High Dam power project has a theoretical generating capacity of 2.1 GW, although low water levels often prevent it from operating anywhere near design capacity. An ongoing refurbishment program is expected to extend the operational life of the turbines by about 40 years and increase generating capacity at the dam to 2.4 GW. The remaining hydropower sites are considered very modest when compared to the Aswan sites.

### *4.2. Renewable energy resources and potentials*

#### *4.2.1. Solar energy*

According to the 1991 Egyptian Solar Radiation Atlas, the country averages between 5.4 and more than 7.1 ($kWh/m^2$) of annual daily direct solar radiation, from north to south [30], see Fig. 8. The annual direct normal solar irradiance ranges from 2000 $kWh/m^2$ to 3200 $kWh/m^2$, rising from north to south, with a relatively steady daily profile and only small variations in resource. Such conditions are supported by 9–11 h of sunlight/day, with few cloudy days throughout the year. Thus, Egypt has very favorable solar resources

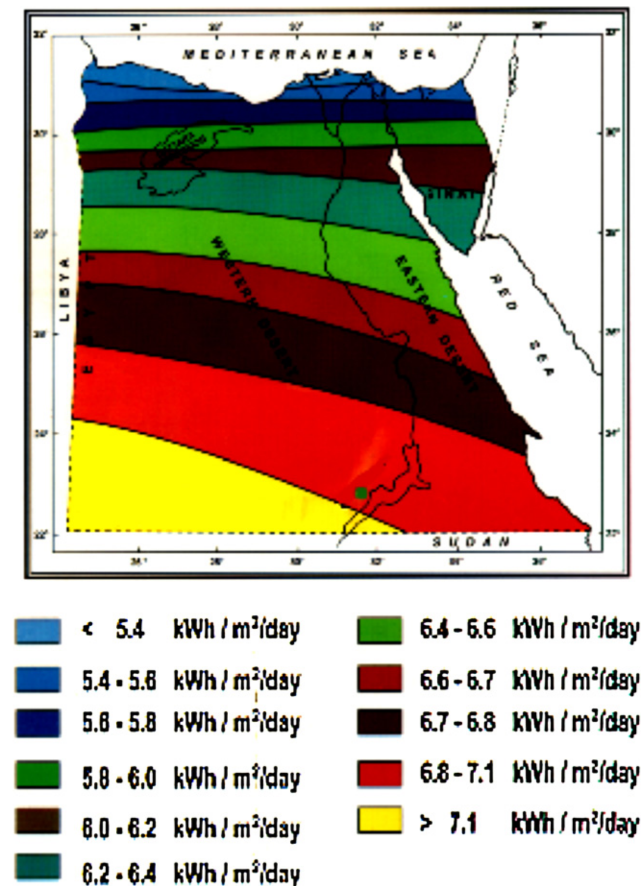


**Fig. 8.** Distribution of solar energy generation potentials in Egypt.

for a variety of solar energy technologies and applications. Both the Solar Radiation Atlas and the German Aerospace Center estimate Egypt's economically viable solar potential in the range of 74 billion MWh/year, or many times Egypt's current electricity production [31].

The Energy Research Center at Cairo University's Faculty of Engineering estimates that 6 MW of solar PV are currently installed in Egypt. In addition, a 150 MW integrated-solar combined-cycle power plant is under construction in Kureimat, with a solar component of 30 MW.

#### *4.2.2. Wind energy*

The first phase of the Wind Atlas for Egypt was finalized in March 2003 with the publication of the detailed Wind Atlas for the Gulf of Suez [17]. This atlas includes wind data for 13 sites covering the decade from 1991 to 2001. The second phase of the project, the Wind Atlas for Egypt: Measurements and Modeling 1991–2005, was released in 2006, covering Egypt's entire land area based on a comprehensive eight-year wind-resource assessment [32]. The purpose of the Wind Atlas was to establish a meteorological basis for assessing Egypt's wind energy resources in six designated regions: the northwest coast, the northeast coast, the Gulf of Aqaba, the Gulf of Suez, the Red Sea, and the western desert.

According to the Wind Atlas, the western part of the Gulf of Suez is home to some of Egypt's best wind resources. Here, average yearly wind speeds surpass 7 m/s, and there is potential for some 20,000 MW of wind capacity. The Gulf of Suez is the region where both short- and medium-term plans for Egypt's wind energy developments are focused.

Fig. 9 illustrates the distribution of wind-generation potential in Egypt at a height of 50 m. 36 Pink, red, and purple areas indicate

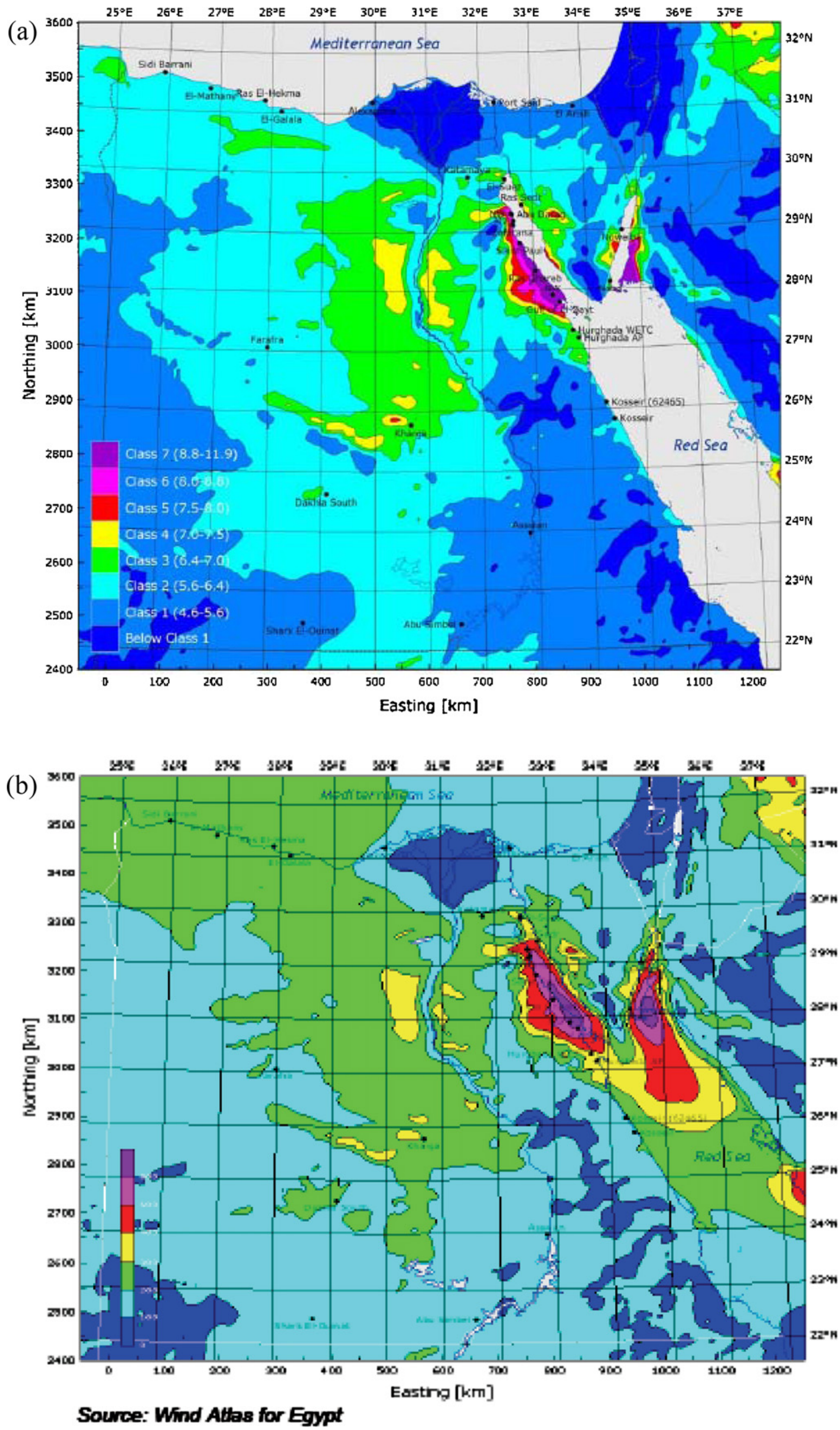


**Fig. 9.** Potential of wind energy in Egypt [14].

areas with economic potential for wind energy generation, while yellow areas represent marginal ones. Already, Egypt has a plethora of wind farms in the Zafarana region along the Red Sea, with a total installed capacity of 430 MW. Meanwhile, a solid plan for an additional 280 MW of installed capacity in this region is under way. Plans for two plants of 120 MW each, and one 200 MW plant, are also being pursued in Zafarana and Gulf El-Zayt with assistance from Germany, Japan, and Spain, respectively. A long-term plan for increasing national wind-farm capacity to 7500 MW by 2020 exists and has been approved by Egypt's Supreme Council of Energy (SCE) [33].

Among other renewable resources wind and solar energy offer significant potentials for the energy problem solving in Egypt. Egypt is endowed with an abundance of wind energy resources especially in Suez Gulf area which considered one of the best sites in the world due to high and stable wind speeds. The West of Suez Gulf Zone is the most promising sites to construct large wind farms due to high wind speeds which ranges between 8 and 10 m/s in average, proximity to load centers and transmission infrastructure, and availability of large uninhabited desert area. There are also other promising sites having wind speed of 7–8 m/s in the east and west of Nile river near Beni Suef and Menia Governorates and El-Kharga Oasis in the New Valley Governorate. Nonetheless, the geographic concentration of large wind farms is expected to be one of the main challenges that need to be adequately studied and addressed before large scale development takes place. Solar energy is also rather abundant. Due to its geographic location, Egypt enjoys sunshine all year, with direct solar radiation varying between 1970 KWh/m$^2$/year and 2600 KWh/m$^2$/year.

The present energy strategy (the resolution adopted by supreme council on energy in 2007) aims at increasing the share of renewable energy to 20% of the energy mix by 2020. This target is expected to be met largely by scaling-up of wind power as solar is still very costly and the hydro potential is largely utilized. The share of wind power is expected to reach 12%, while the remaining 8% would come from hydro and solar. This translates into a wind power capacity of about 7200 MW by 2020. The solar component is at this stage considered to start with 100 MW of CSP and 1 MW of PV power [4–6].

Financing of large scale wind and solar development faces a variety of challenges due to the size of the required investment and the need for some type of subsidy. Worldwide, investments in renewable energy are made through various subsidy mechanisms including feed-in tariffs, soft loans, tax credits, etc. Following the new energy draft law, Egypt will be using a combination of these instruments in order to utilize donors support during the investment phase while also providing incentive to the private sector for participation in public-private ventures.

Egypt has been successful in tapping international support for renewable energy projects. AfDB is playing an important role in financing both wind and solar programs. Other DFIs including KfW, EIB, the World Bank and the International Finance Corporation are equally involved in supporting the required investments. The Clean Technology Fund (CTF) provides support through the AfDB and the World Bank to the development of wind and solar plants and the associated transmission projects. The wind program has been supported by Germany, Denmark, Spain and Japan. Plants under construction and preparation are also being financed by Germany, Japan and Spain, as well as the European Investment Bank [7–9].

*4.2.2.1. Numerical wind atlas.* With 30 meteorological stations it is only possible to map the wind resource in detail over a few tens of thousands of square kilometers with an observational wind atlas.

Numerical wind atlas methodologies have been devised to solve the issue of insufficient wind measurements. For Egypt, we have used the so-called KAMM/WAsP method developed at Risø. The KAMM (Karlsruhe Atmospheric Mesoscale Model) is a mesoscale model that models the wind flow on a much larger scale than the wind atlas model WAsP; typical domain sizes are between 100,000 and 1,000,000 km$^2$.

The mesoscale model works much like a weather forecast model – in the sense that it estimates how the terrain influences the wind flow and other characteristics of the atmosphere – but the models are employed in different ways. The weather forecast model uses an analysis of today's meteorological observations in order to produce a weather forecast, while the mesoscale model can use sets of historical analyses in order to estimate the mean meteorological conditions over the entire modeling domain. For Egypt, a using of statistics of the large-scale meteorological situation for 34 years to estimate the long-term wind conditions in the grid points of the mesoscale model is designed. The distance between these grid points is 7.5 km for the two domains that cover all of Egypt, corresponding to more than 50,000 grid points in the domains. Based on these estimates of the wind climate, we can draw a wind resource map of Egypt, see Fig. 9. The wind resource map provides an overview of the climatological wind conditions over Egypt, but the accuracy in the resource estimates for any specific site is limited because it does not take all the small-scale features of the terrain into account; the map is based on simple interpolation between the grid point values.

This inherent limitation of the mesoscale model results can be overcome by transforming the wind resource map into a wind atlas map – or a numerical wind atlas – which can then be applied with a microscale model to reliably estimate the wind resource at any site within Egypt. Conceptually, the mesoscale modeling therefore corresponds to covering Egypt with over 50,000 'virtual met stations' from which the regional wind climates can be determined. The numerical wind atlas is thus a database of regional wind climates and the Wind Atlas for Egypt contains exactly 54,897 regional wind climate data sets that can be employed directly with the WAsP microscale model for resource assessment and siting all over Egypt.

*4.2.2.2. Verification.* Since the observational and numerical wind atlases both result in estimates of the regional wind climate – i.e., the wind climate that would have been measured at a site if the terrain was flat and homogeneous and without any nearby obstacles – the regional wind climate values can be compared at the locations of the meteorological stations. Comparisons for six different domains in the Wind Atlas for Egypt indicate that the mean absolute error (the difference between the two estimates divided by their mean value) is typically around 10% for the two large-scale domains which cover all of Egypt, see Fig. 10. For four smaller regional domains, the mean absolute error is typically around 5%, see Fig. 11. The numerical wind atlas is less accurate in regions where the horizontal gradients in the regional wind climate are large, e.g., in the southern part of the Gulf of Suez and the northern part of the Red Sea, and also close to the domain boundaries.

However, the generally good agreement between the regional wind climates derived from mesoscale modeling and from observations adds confidence to the KAMM derived wind statistics for locations away from the meteorological stations.

## 5. Photovoltaic market and supply chain in Egypt

This section examines the photovoltaic market and related aspects in Egypt, as well as the supply chain. System specifications for PV components, battery banks, and the PV theory of operation with its significant influence on the cost and future of the technology are discussed in Appendix A.

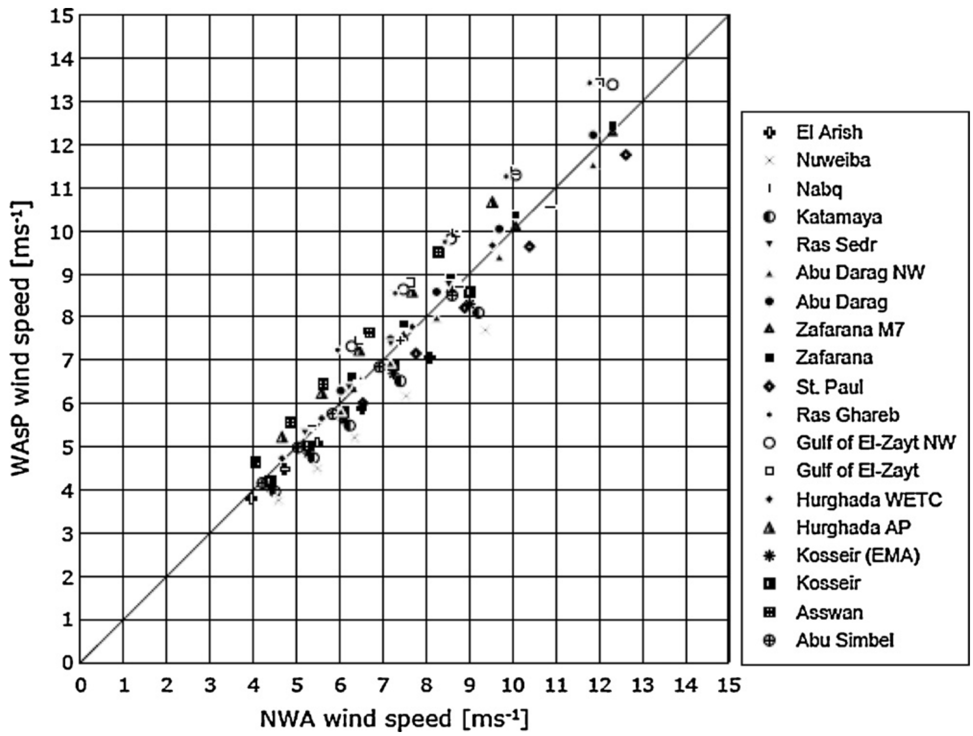


**Fig. 10.** Eastern Egypt domain (resolution 7.5 km) comparison of atlas wind speed values at 10, 25, 50, 100, 200 m calculated using KAMM/WAsP (*x*-axis) and observations/WAsP (*y*-axis), roughness is 0.03 m [14].

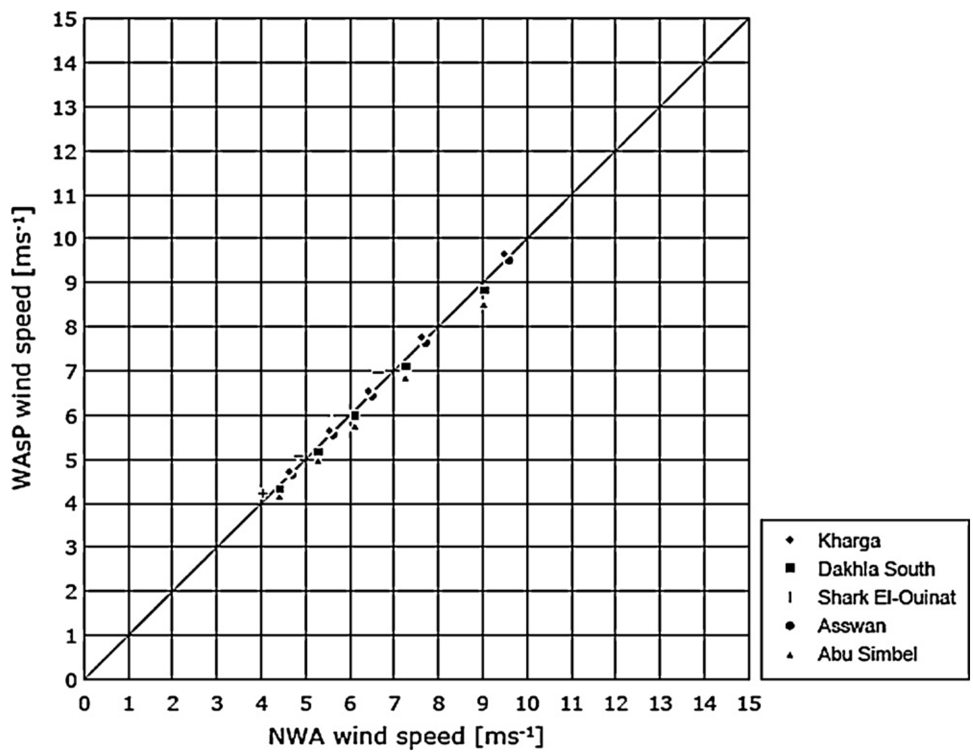


**Fig. 11.** Western Desert domain (resolution 5 km) comparison of atlas wind speed values at 10, 25, 50, 100, 200 m calculated using KAMM/WAsP (*x*-axis) and observations/WAsP (*y*-axis), roughness is 0.03 m [35].

### *5.1. PV market in Egypt*

There is limited demand for PV in the Egyptian market to date. The market is characterized by a limited number of SME service providers, most of which are private enterprises driven by the visions of their own entrepreneurs rather than by local and regional market forces.

#### *5.1.1. PV market size*

Exact figures for the size of Egypt's PV market are not available. However, a 2006 study by Cairo University's Energy Research Center indicated that one particular producer holds a 5% share in the Egyptian market [34,35]. According to sales figures for this producer in installed kilowatts over the last eight years, average sales during the period 2004/2006 were 26.5 kW/year. With the average

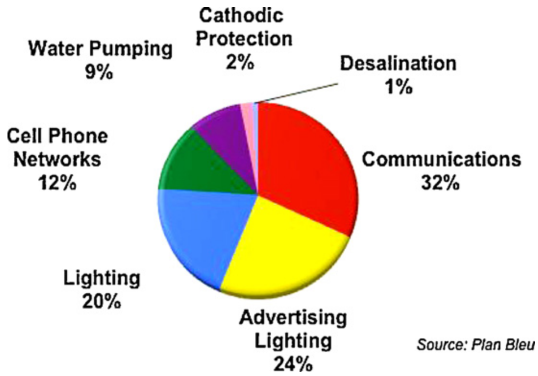


**Fig. 12.** PV applications in Egypt by usage (4000–4500 $KW_p$).

price per installed kW of PV modules estimated at 40,000 Egyptian pounds, this would make the total market size in 2006 about 21 million Egyptian pounds.

The above producer's average local sales in the period from 2007 to early 2009 are in the range of 15 kW/year. Several of these recent projects have been commissioned by international clients and donors. Assuming that the producer's market share has remained constant, the current market size (2009) would be 12 million Egyptian pounds.

These numbers are obviously rough approximations, but it is safe to say that the local PV market size is in the tens of millions of Egyptian pounds—a rather limited market given Egypt's solar potentials and coming energy-supply situation. All of the stakeholders interviewed in this study firmly asserted that Egypt's PV market is very well saturated under the current institutional conditions (i.e., the lack of a regulatory push for PV combined with fossil fuel subsidies and their relatively low upfront capital costs).

*5.1.2. Market drivers*

The main drivers of PV sales in Egypt are telecommunication systems, remote and inaccessible low-voltage needs, and highway billboards for advertisements [36], see Fig. 12. Both the telecom and billboard markets witnessed a boom in 2004–2006. Several interviewees for this study noted that the PV market has since slumped. Future expansion in telecommunications and highway construction would boost market turnover, depending on the size of expected projects.

According to interviewed PV suppliers, clients are adopting PV systems in industrial and residential facilities as a way to avoid the progressive tariff related to the increase in total peak load. Supplying the loads in part via PV reduces the overall energy cost for the facility and can provide a very good return on investment. An industrial client with high energy consumption could expect a payback on their investment in the PV system over 5 or 8 years with a very low discount rate, usually 5%.

Another mentioned driver of PV demand is convenience, in the case of remote applications or difficulties with accessibility. For example, PV is the most suitable power supply for highway billboards that are located far from the low-voltage distribution grid. Such investments could also make good economic sense. Convenience and the avoided risk of oil spills from generators might drive demand in the niche market for farm lighting.

There is only limited demand for PV from engineering applications, such as for desalination. This could be attributed to the lack of awareness on the part of clients regarding the scope and potentials of PV, or it could be because PV is not feasible in such cases, whether economically or in terms of power-supply reliability. Further investigation and research into engineering applications could augment demand in this niche market.

In some instances, using PV to present an image of environmental consciousness, while perhaps not financially viable, is part of a marketing strategy, as in the case of tourist facilities seeking "green" labels. Other minor applications of PV include demonstration cases, such as projects financed by international donors or environmental organizations.

*5.1.3. Competition from alternatives, and PV costs*

The main competitor to PV under prevailing institutional conditions is diesel oil generators. Most economic feasibility studies currently favor the use of fossil fuel generators. A 1999 World Bank study of rural electrification in some 100 remote Egyptian villages concluded that a diesel-generator mini-grid is more competitive than PV.48 A 2001 World Bank study comparing energy prices for water pumping on desert farms in Egypt similarly found that PV systems cost 2.79 cents/pumped $m^3$, whereas subsidized diesel oil generators cost 1.34 cents.49 The study included the cost of maintaining generators but not the impacts of the diesel subsidy.

In contrast, some interviewed experts assert that PV is more competitive than diesel oil, based on some feasibility studies conducted; however, these analyses calculate in the costs of externalities such as carbon dioxide emissions and environmental pollution—a measure that investors seldom, if ever, undertake. Externalities are usually internalized by government or donor-funded projects since their estimates are based on socio-economic feasibility studies that emphasize environmental issues. Notwithstanding the limited demand for solar PV, Egyptian suppliers work in a variety of PV applications.

*5.2. Global and Egyptian PV supply chain*

*5.2.1. Global supply chain*

PV supply-chain components are highly compact—much more so than the components for wind energy. For PV systems, the pivotal product is photocells, which involve highly specialized semiconductor technologies. Intensive research is being undertaken to overcome the cost barriers that hamper widespread use of this technology. Although new production methods are bringing down the cost of photocells, problems remain with regard to cell efficiency, lifespan, stability, and degradation. The pace of technological development is moving rapidly due to the growth of new thin-film technologies, boosted by the short-term global shortage in silicon supply and by advances in material science.

This technological boom is increasing competition and putting pressure on PV developers and producers to consolidate the supply chain through long-term agreements and vertical integration. The Spanish manufacturer Isofoton, for example, produces all PV-system components, from cells to inverters and batteries, and the German manufacturer Q-Cell engages in contracting, consultancy, and system integration. Japanese producers such as Sharp and Mitsubishi have a structural focus on vertical and horizontal integration in their national institutional structure. Broad product diversification is very common among gigantic entities in Japan.

The European trend towards supply-chain consolidation is spurred by overcapacity and is supported by the nature of supply chain products and technologies as seen in Fig. 13. Coating materials and tracking systems are not very technologically specific, nor do they require a high level of market specificity. For the batteries and the balance of the system, which are significant components both size- and cost-wise, the level of market and technological specificity is even less.

In the technologically less mature developing-country markets, which are characterized by adequate availability of solar radiation, system integrators and/or service providers have considerable input into PV technology. Their familiarity with local markets,

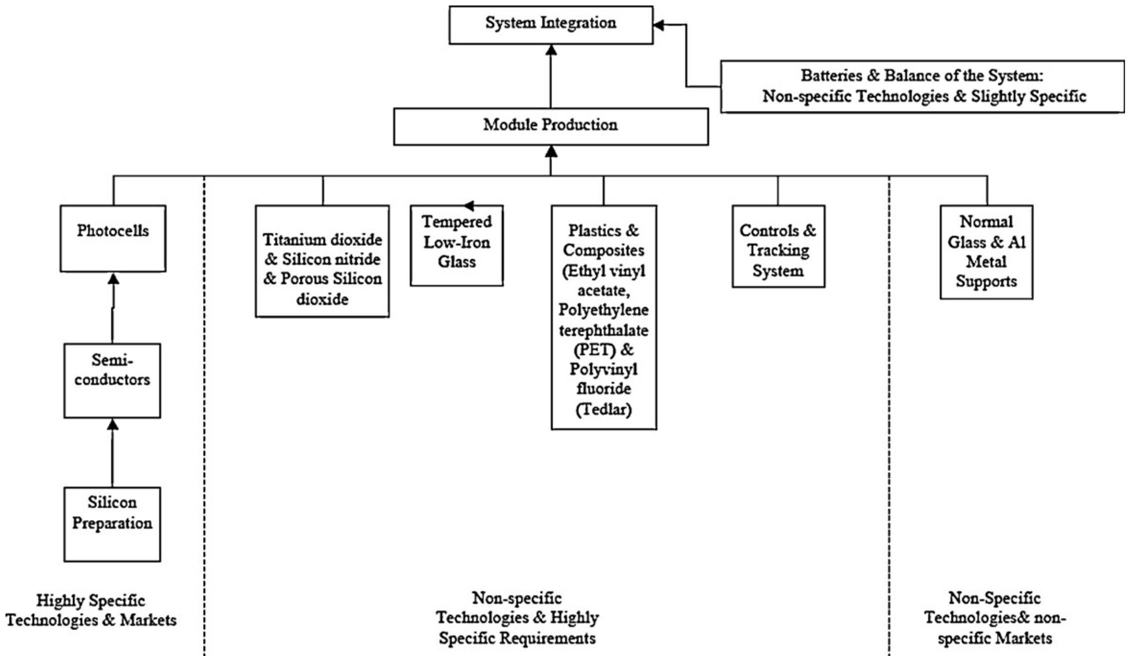


**Fig. 13.** Photovoltaic supply chain components.

institutions, knowledge, and business networks renders them a critical component in the value chain. This also explains in part the global trend towards supply-chain consolidation, as major photocell producers, driven by overcapacity, attempt to gain a strong footing in new markets using local partners.

Despite the low technological specificity of some of the main PV system components, such as balance of the system, the number of Egyptian companies that manufacture inverters, power electronic equipment, and control systems is modest. Some local production capability does exist in the electronics field; however, only about 185 companies, representing 0.5% of the global market, work in this field in Egypt, focusing mainly on consumer electronics. This is because of weak input industries such as integrated circuits and the dependence on low-level technology licensing.

Other components of the balance of the system, such as switch gears and cables, are commonly produced in Egypt at a quality that allows them to be exported to international markets. Aluminium and glass frames and other system auxiliaries are produced in Egypt, with room for quality improvements.

Table 1 provides a summary of PV manufacturing capabilities in Egypt. Clearly, there remains vast potential for developing the industry. With the exception of improving the supply of existing components, developing the local supply chain for specific PV technologies does not appear to make financial sense, given the small size of the market. Once the PV system-integration business has taken off in Egypt, it will be easier to identify precise information about the feasibility of localizing material and supply requirements.

Given the uncertainty of short-term market growth, switching the orientation of the local supply chain towards exports would present sufficient impetus for the industry to improve the preconditions of growth, including R&D. Some Egyptian system integrators export their expertise to Arab and East African countries, capitalizing on regional trade preferences. The array assembler BIC, for example, already exports Egyptian-made modules to other African countries.

## 6. Wind energy market and supply chain in Egypt

This section examines the wind energy market and related aspects in Egypt, as well as the supply chain.

### 6.1. Wind energy market in Egypt

#### 6.1.1. Wind market size

Through donor projects, Egypt has established a series of wind farms in the Zafarana, with a total installed capacity of 430 MW.[54] Most of the farms were implemented during the last decade. Table 2

**Table 1**
An assessment of current and technological potentials of the PV supply chain in Egypt.

| Component | Manufacturer/ potential manufacturer | Manufacturing ability |
|---|---|---|
| Silicon preparation | None | D |
| Wafer production | None | D |
| Solar cells | Arab–British Company for optics and AOI | B |
| Production material for array assembly/ module production | 25% of material is locally produced[53] | C |
| Modules/ array assembly | AOI and BIC for Electronics Environment and Energy | A |
| System integrators [including seriojs potential entrants) | IMF, SOUVTEC, ASET, MEET, Solar Energy and Environment Technology, El-Araby, Sun Prism Energy Technologies. Egyptian Solar Energy Systems Company, Mesalla International Trading Co. | A |

A: Available production with need for further RSD and for technological alliances.
B: Available quasi-experimental production with an international technological alliance.
C: Partly available.
D: Needs extensive know-how investment, R&D. Beyond the current institutional capabilities and level of technological advancement in Egypt

**Table 2**
NREA Wind Farm Capacity in Egypt: Operating and Planned Projects as of October 2008.

| Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Installed capacity | 0 | 30 | 47 | 0 | 85 | 0 | 80 | 120 | 120 | 0 | 320 | 220 |
| Total MW | 68 | 98 | 145 | 145 | 230 | 230 | 310 | 430 | 550 | 550 | 870 | 1090 |

Source: Elsobki et at.

shows the capacity of wind farms installed since 2002, and expected installations through 2013.

A market for smaller wind turbines in Egypt does not currently exist, and there is no real market assessment for the potential latent demand. However, since small turbines could provide alternatives to diesel generators, the market could be very substantial. Small-scale stand-alone turbines have several applications, especially when integrated in a hybrid system that ensures continuous supply.

The substantial potential demand for small-scale turbines was supported by Mr. Sherif ElGhamrawy, who represents Hemaya, an NGO that promotes environmental projects in Sinai and sponsored the erection of two small turbines in the region. Whether this demand is constrained due to inexistent supply, or to a lack of awareness of potential applications and feasibility from the user side, is not known. Moreover, it is not clear whether this latent demand is enough to justify an investment in this industry.

The government is not interested in small-scale wind development, even though it could save on fossil fuel consumption, because its sole focus is on “achieving the Ministry of Electricity plans.” Soft financing (to cover the higher upfront capital investments) and awareness are needed to boost this market. Depending on the application, boosting this market will also require coordination with other entities such as the Ministries of Agriculture or Tourism. These all fall within the tools that the government should use after clarifying its scope of interest.

Even without government intervention, the wind energy market for small-scale turbines could still develop. However, this will require substantial investment in public awareness. One of the interviewees for this study noted that market initiation (and later development) will also benefit from the increased credibility resulting from agreements of local manufacturers to produce under license of international suppliers.

#### 6.1.2. *Current developments in Egypt*

The Egyptian Supreme Council of Energy has approved a long-term forecast for wind energy development to 2020 as shown in Table 3. The official forecast reaches 1000 MW (around 660 turbines) of newly installed capacity/year by 2019. This very ambitious forecast is based on a transition from NREA-dominated development to private sector development.

The first steps in the process of mobilizing private funds for wind-farm development have been taken recently. However, given the substantial delays in undertaking these steps, there is a high level of scepticism in the market about whether the forecast will materialize as expected.

Egypt’s officially announced target is to increase wind energy’s contribution to total electricity generation to 12% by 2020. This has encouraged local investment in manufacturing relevant components.

Given short-term plans reflected in Tables 2 and 3, local demand should materialize soon (100–120 towers/year). As mentioned above, plans for two 120 MW plants and one 200 MW plant are being coordinated with German, Japanese, and Spanish assistance, respectively, in Zafarana and Gulf El-Zayt, to be owned and operated by NREA.

### 6.2. *Global and Egyptian wind turbine supply chain*

#### 6.2.1. *Global wind turbine supply chain*

The more complex and varied nature of the wind-energy supply chain keeps its global supply chain more diverse. This is because of the long list of products with various technologies that must be modified for wind turbine manufacturing. Some of these technologies are highly specific to the wind-turbine industry.

The supply chain of wind turbines is vertically large when compared to other RE systems such as PV and biomass. A large share of system components is either technology- and market-specific, or technology non-specific but with specific requirements as in Fig. 14. Even for supply-chain components that are not technology specific, such as hubs and frames, towers, and control systems, the level of tooling up and gearing production towards meeting the specific requirements of these products is high.

The high level of specificity in the wind energy supply chain explains in part the global shortage of gear-box bearings and other components, as component manufacturers do not necessarily prioritize wind energy [37–40]. The trend among international suppliers is to build factories in labor-cheap countries such as Romania and India. Notwithstanding the large size of the wind-energy supply chain, many of the components in this chain are knowledge intensive.

## 7. Summary profile of PV and wind energy supply sectors

### 7.1. *Contextual impacts on the local renewable energy market*

Currently, all players in Egypt’s RE market are exhibiting anticipation and anxiety fuelled by a desire to capitalise on the country’s expected transition away from cheap and readily available fossil fuels. This sentiment is accentuated by the proposed new electricity law, for which approval and ratification is expected to be imminent.

The new law will set up an institutional environment more conducive to RE. It will provide comprehensive mechanisms for liberalisation of the energy market and decentralisation of energy distribution and transmission. It is expected to bring energy tariffs closer to real market prices by allowing private low- and medium-voltage traders and private generators to produce and sell electricity through the transmission company. This private-sector participation means that portions of the massive subsidies will be lifted to lay competitive grounds for private traders.

**Table 3**
Tentative schedule for installed wind farm capacity, 2011–2022.

| Year | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New capacity | NREA private | | 320 | 220 120 | 500 | 500 | 750 | 900 | 900 | 1000 | 1000 | 1000 | 1000 |
| Total MW | | 550 | 870 | 1210 | 1710 | 2210 | 2960 | 3860 | 4760 | 5760 | 6760 | 7760 | 6760 |

Source: Elsobki et at.

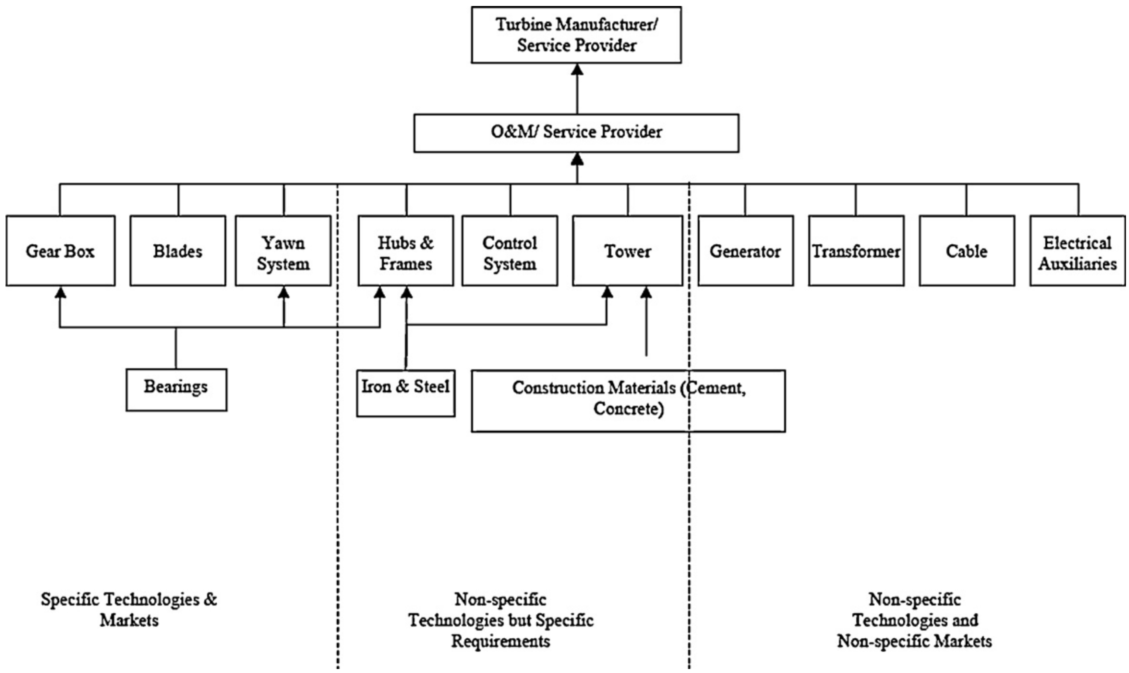


**Fig. 14.** Wind turbine supply chain components.

Both customs-tax incentives for RE-specific components and financial support mechanisms exist. However, these are limited in scale and scope. Moreover, the latter are mostly environment-oriented funds that are directed almost exclusively towards industrial users.

The new law should strengthen these incentives. It will regulate market demand conditions favorable for RE development in two ways: (1) by reserving a quota for RE bulk power production, and (2) by eliminating part of the unfair comparison of RE to conventional power sources by bringing conventional energy prices closer to real costs. Feed-in tariffs will be introduced in a second phase after a learning period of competitive bidding for a predetermined RE quota in the government's bulk power production.

Such institutional changes are being driven by an anticipated local energy crunch fuelled by dwindling fossil fuel reserves. This crunch comes in a global context where resources are being mobilized towards support of RE take-off. Both the international and local energy contexts confirm that, during the coming decade, Egypt will witness a higher RE contribution to its energy portfolio.

Nevertheless, information gaps remain regarding the timeframe of the law. It calls for a phased approach to implementation of the proposed mechanisms; however, it does not provide an estimate of the learning period for competitive bidding before the shift to feed-in tariffs. The government also has not put forward a schedule for its new electricity tariff plans. There has been no elaboration on the implementing structures of the new electricity law and the associated new market mechanisms. Criteria for assigning low- and medium-voltage traders and distributors have not been clarified in the draft law.

## 8. Conclusions

Egypt has good potential of PVs and wind powers. A total of 20 GW installed electric power can be generated by building wind farms along Gulf of Suez and Red Sea costs. The total wind electricity generated by 2022 (3.53 GW) would represent 8.8% of the 40.2 GW total electric power expected to be installed at that time. Taking in consideration other renewable forms of energy (hydropower of 2.9 GW and solar of 1 GW), the renewable content at 2022 may reach 7.4 GW representing 18.4% of the total installed power. This contribution will add significantly to country's energy sustainability.

## Appendix A. PV system primer

### A.1. System components

*Raw materials for semiconductor or PV cell production*: Include silicon of different crystalline structures; polycrystalline thin films such as copper indium diselenide, cadmium telluride, and thin-film silicon; and single crystalline thin films such as gallium arsenide.

*Module*: Consists of a rear layer, a transparent material around the outer surface, an encapsulant, and a frame around the outer edge. Usually the top surface is made of tempered low-iron glass; encapsulant is made of ethyl vinyl acetate (EVA); and polyvinyl butyral is used in case of glass back layers, resin pottants, or borosilicate glass. The rear layer is usually Tedlar-PET-Tedlar sheet. The frame is usually made out of aluminium. Several materials form the anti-reflection surface coatings, such as titanium dioxide, porous silicon dioxide, and silicon nitride. A substrate surface provides structural support at the back and is usually made from metal or glass.

*Concentrator*: Made up of metal housings and optical plastic lenses.

*Tracking system*: Comprises control system and electric motors along with their drives and controllers.

*Battery charge controller*: Used to protect the battery against overcharging that will end its life. It also cuts the battery off the load when discharged beyond its discharge limit. At present, three-stage charge controllers are gaining momentum in the market. They control the amount of charging current reaching batteries.

*Balance of system*: If the system is working in a stand-alone mode, batteries are used with the system to store energy and ensure continuous supply of DC load along with a charge controller, or AC load after the use of inverters. The system can be used without batteries, where inverter units and power quality units are used to ensure continuous supply. The converter/inverter units along

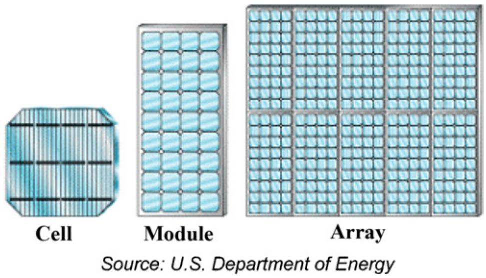


**Fig. A1.** Connected PV cells.
Source: U.S. Department of Energy.

with batteries, cables, and conduits are called the "balance of the system."

### A.2. Theory of operation

A PV cell is basically a semiconductor that absorbs solar energy (sunlight) and converts it into electric energy. The incident light falling on a P–N junction of a silicon semiconductor provides the electrons in this zone with sufficient energy to become free flowing. Thus, an electric current is generated. Several PV cells are connected together to form a PV module, which can reach several meters in size. Modules grouped together form arrays that provide output electric power of different magnitudes, as illustrated in Fig. A1. The power is stored in batteries. The PV modules, together with the mounting structures, power electronics units, batteries, and sun tracking system, put together, make up a PV system.

The PV system is either flat-plate or concentrating. A concentrating system focuses incident sunlight from large areas to smaller ones in order to reduce the number of expensive PV cells needed. The most common system type is flat-plate. Panels track sunlight via an automated one- or two-axis tracking system. In the case of grid-connected systems, a control panel is installed that has a power direction relay to supply needed power from the grid when the application loads exceed the PV system capacity. It also balances the power supplied to the grid in case it is shut down or fully charged. Most inverter units that convert the DC output of batteries or modules to AC shape the frequency and voltage output of the system to suit the specifications of the grid.

### A.3. Broad specifications and standards

Photovoltaic cells are specified by the total installed capacity of the system in watts. The modular structure of the PV system makes it capable of supplying any rated power from very small to huge (560 MW) amounts. The PV system price is supposed to be solely a function of rated power, regardless of size. Different wattage/m$^2$, however, comes with different systems depending on the efficiency of the photocell, materials used, and solar radiation. Regulation and financial schemes that promote RE are fuelling R&D in photovoltaics, working on improving cell efficiency via innovative manufacturing methods and technologies. The aim is to improve overall PV system reliability and convenience and reduce the cost of photocells, which along with batteries comprise 90% or so of the total system costs

Standards for PV systems are not complex and fall into four categories:

- Design quality standards, which include electrical connections, wiring, earthing and protection, switch gear (adopted from local codes), as well as mechanical standards for module-mounting structures, accessibility of system components, material suitability for different working and weather conditions and building materials (in the case of roof-mounted), and safety and instrumentation.
- Standards for performance and ratings of major system components, such as battery performance, inverter power ratings and protection, and chargers.
- Module performance at short and open circuit, conformance to voltage and power design ratings, and compatibility of all the system components with each other.
- Photocell and module assembly production standards.

### A.4. Battery

#### A.4.1. Battery bank

Batteries, together with photocells, make up about 90% of the total cost of PV systems. The battery is a decisive factor in the overall system reliability because it determines, along with the number of modules, the size of the system and the appropriate locations. The battery bank is usually made up of 12-V units (2-V batteries are used for simple applications such as toys). The overall available voltage coming out of the system is either 24 or 48 V. Battery banks for PV systems are specified by their A-h over the specified discharge period for reasons of convenience for comparing with other batteries, which is an indication of energy storage capacity. Depending on voltage, it could be converted to kWh.

Batteries used in PV systems are mostly lead-acid batteries similar to vehicle batteries; however they are mostly manufactured specifically for PV. They are usually deep-cycle batteries to withstand being discharged to 80% of their capacity without being damaged. They are mostly sealed batteries to do away with service requirements. The most common type today is Valve Regulated Lead-acid Batteries (VRLA). They are mostly AGM VRLA batteries that are able to fit in tight places and are spillage-proof due to the nature of the electrolyte used (borosilicate glass). AGM batteries are preferred to gel-cell VRLAs that work for the same applications, due to shorter charge time and lesser capacity-loss rates as well as its storage of more power in lesser sizes. Shallow-cycle batteries, which can be discharged to only about 25% of their full capacity, can be used in small PV systems provided that they have been significantly over rated to increase capacity.

The common lifespan of a PV battery ranges between 3 years and 10–15 years in the best scenarios. The meticulous requirements of PV systems and other remote power systems have led battery manufacturers to produce models specifically for PV systems. The lifespan depends on temperature, charge/discharge cycle, and other parameters specified by design and production. Flooded batteries similar to those used in vehicles can also be used, as they have better lifespan performance as well as lower capital costs. Yet they comprise a convenience burden due to their battery service requirements and use hazards; they are almost phased out in the PV market.

The auto industry is sponsoring extensive research to improve the size and cost considerations of batteries. This, in turn, according to a consultant from the German Solar Energy Association, will serve to propagate PV technologies due to anticipated massive optimisations in battery sizes and costs over the long term. Research is also under way on innovative energy storage technologies such as underground flywheel and Vanadium Redox Batteries (VRBs). VRBs have a theoretical infinite charge/discharge cycle, where energy is solely stored in electrolyte rather than charged plates, thus battery capacity could be increased by pumping more electrolytes from an underground storage tank or so. The future of PV as a major reliable power source is dependent on the advances of R&D in batteries and photocell technologies.

### A.5. Production and assembly

#### A.5.1. Photocell production

The most common production method for photocell production is to prepare and clean PV grade silicon or other material and then grow it into crystalline structures by pulling from molten mould: ingot. These are then cut into wafers, or semiconductor circular discs. The wafers receive electric and chemical structures and treatment, such as doping of n-p junctions, and are then connected electrically to produce solar cells. The most recent of these methods, which might lead to significant cost reductions, is thin-film technologies that involve depositing non-crystalline silicon material on inexpensive substrates. Amorphous silicon may be deposited on stainless steel ribbon, or copper indium gallium diselenide (CIGS) alloy cells may be deposited on glass or stainless steel substrates.

#### A.5.2. Module assembly

PV modules are commonly assembled using soldering to bond the component metals.

Assembly generally involves two stages. The first is to solder photocells together in clusters f 6–10 in a process called cell stringing; the cells are connected by 2-mm ribbons known as stringing ribbons. Solder-coated tabbing paste is either dipped into flux (to prevent oxidation of soldered joints) or printed onto PV cells. The soldering of cells to the stringing ribbon is carried out by a tabbing machine (using infrared) or by a soldering iron.

In the second stage, the photocell clusters are soldered to a "bus ribbon" that carries electric current to the output of the module. This stage occurs after the cells have been strung together and placed on a substrate, usually glass. Iron solders are typically used in this process. The clusters are interconnected to form modules of 20–80 cells each.

After the cells have been "tabbed" and "bussed," a layer of glass is placed over them and a coating is applied. Finally, the module is sealed and tested for efficiency.

#### A.5.3. System integration

A system integrator installs the PV system for the application at hand. Integrators determine the placement of the PV module (roof, a shade structure, or building-integrated PV) and the material used in mounting. They ensure that local electrical and building codes are properly followed. The customer provides both an estimated and warranted energy output, based on actors that include the module's technical specifications, the on-site meteorological conditions, dust concentration, and the shading produced by surrounding structures. When batteries and inverters are used, the system integrators size and rate the balance of the systems. In the case of grid-connected systems, they make sure that the applied PV grid connection standards are strictly followed.

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